Characterizing Energy Response for the Daya Bay Antineutrino Detectors

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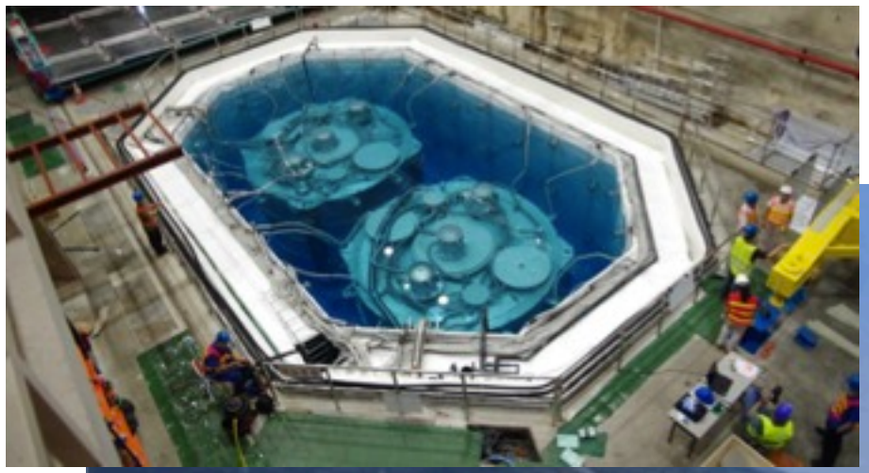
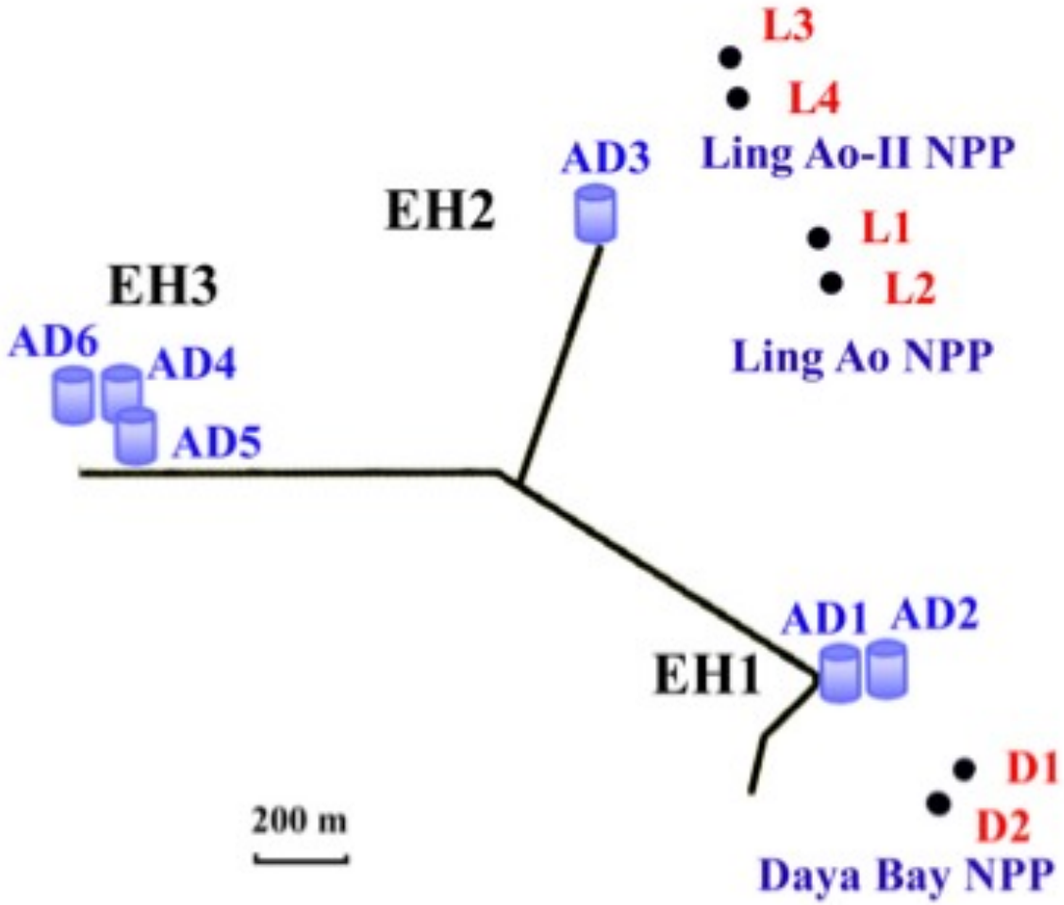
On Behalf of Daya Bay Collaboration

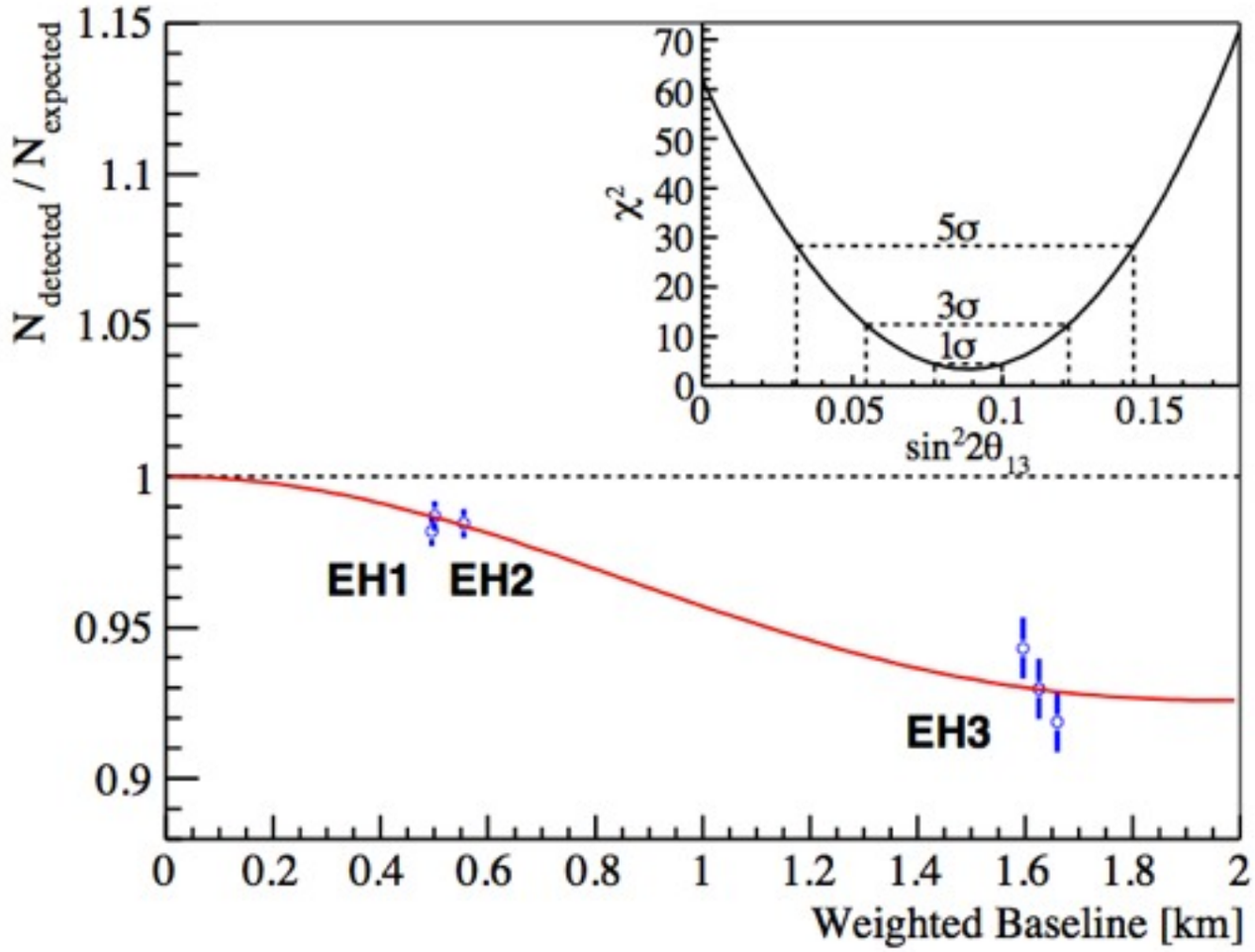


The Daya Bay Experiment

Detect short-baseline reactor antineutrino disappearance

$$P_{13} \approx 1 - \sin^2 2\theta_{13} \sin^2 \left[1.27 \Delta m_{13}^2 (eV^2) \frac{L(km)}{E_\nu (GeV)} \right]$$





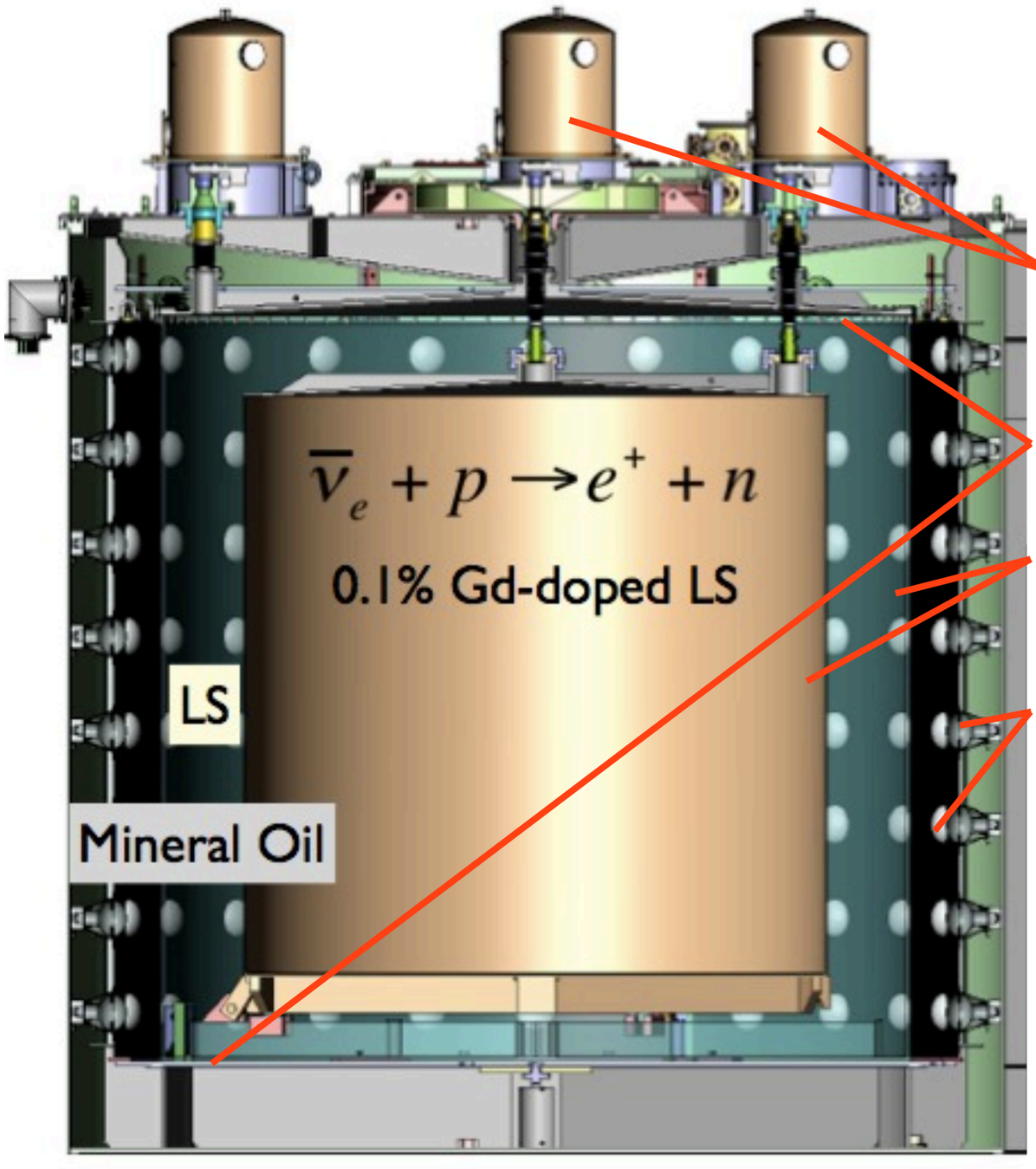
$\sin^2(2\theta_{13}) = 0.089 \pm 0.010(\text{stat}) \pm 0.005(\text{sys})$

The most precise measurement of $\sin^2 2\theta_{13}$ to date

CPC **37**, 011001 (2013), arXiv:1210.6327

The Daya Bay Antineutrino Detectors

8 deployed 'identical' 3-zone detectors

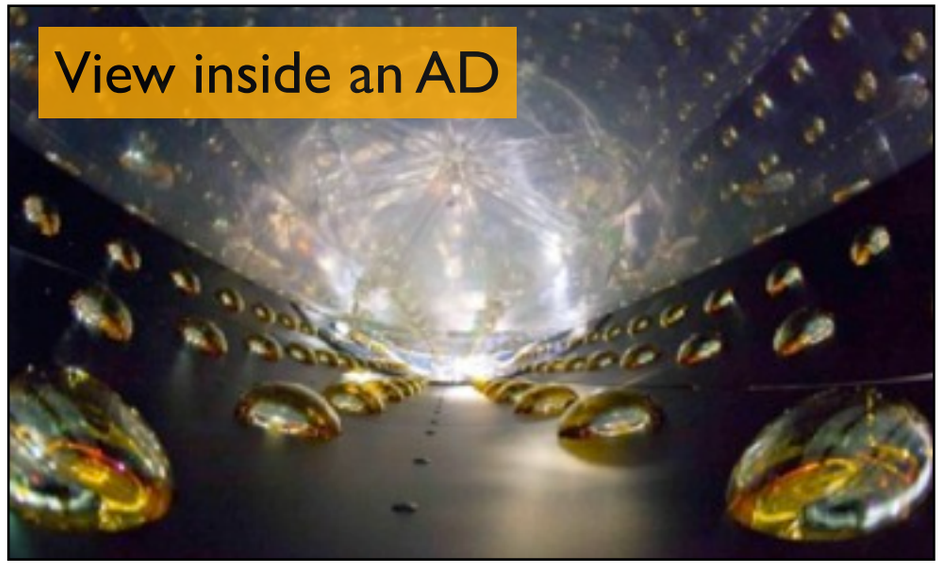


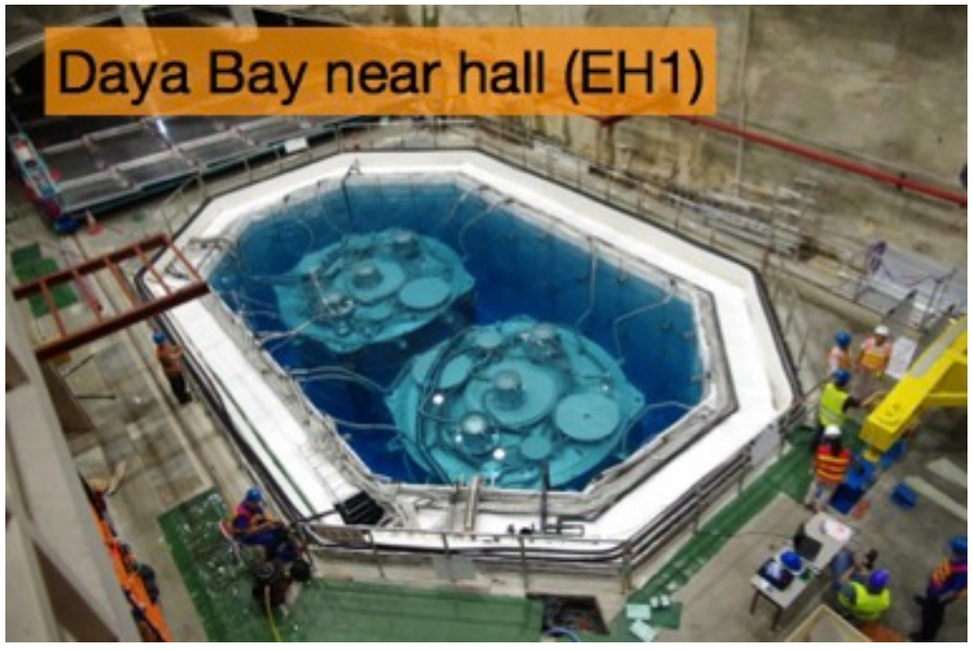
Automated Calibration Units (ACUs)

Reflectors

Acrylic Vessels

192 8" PMTs



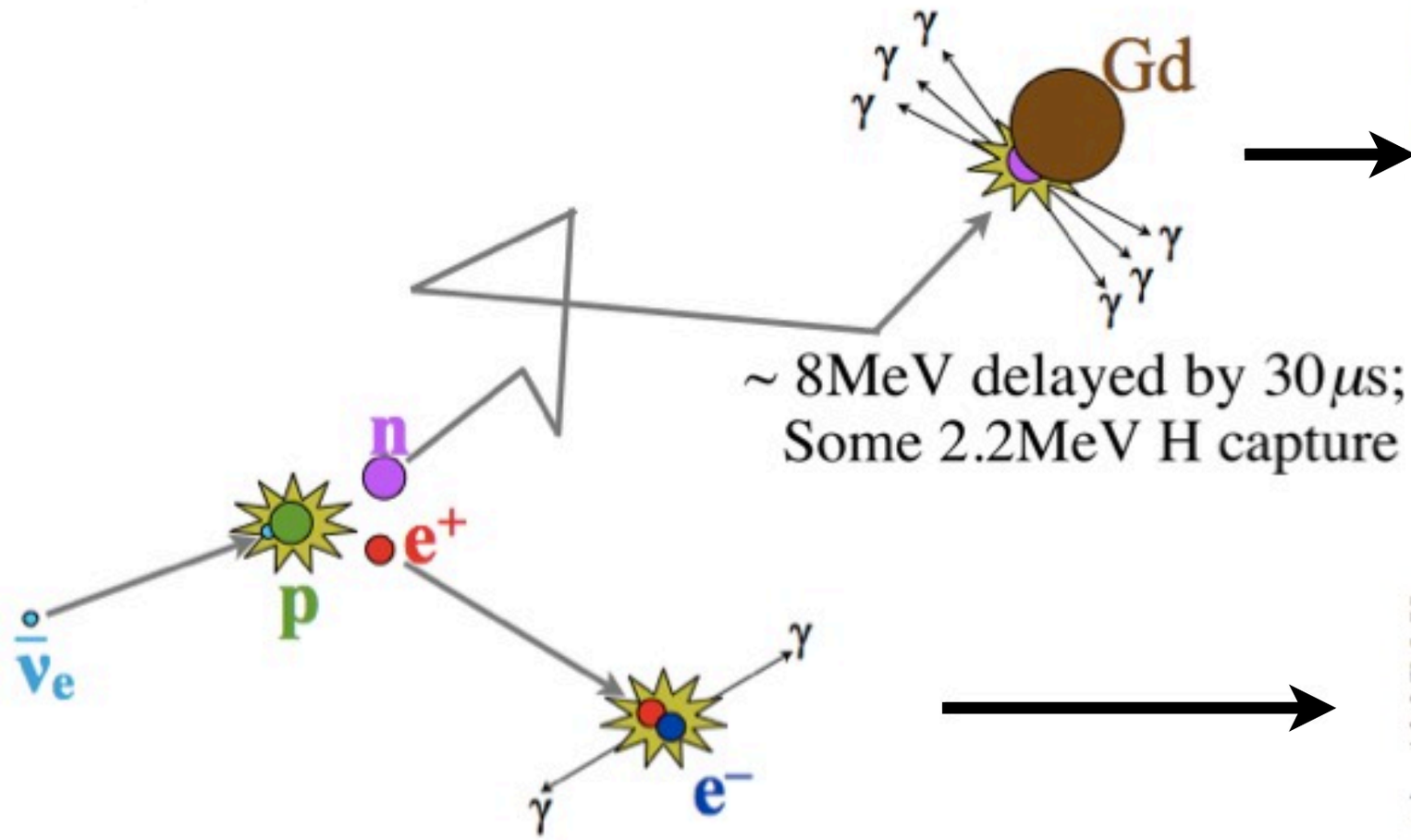


Target Mass: 20 tons
Energy Resolution: ~8%\√E
Light Yield: ~165 photoelectrons/MeV

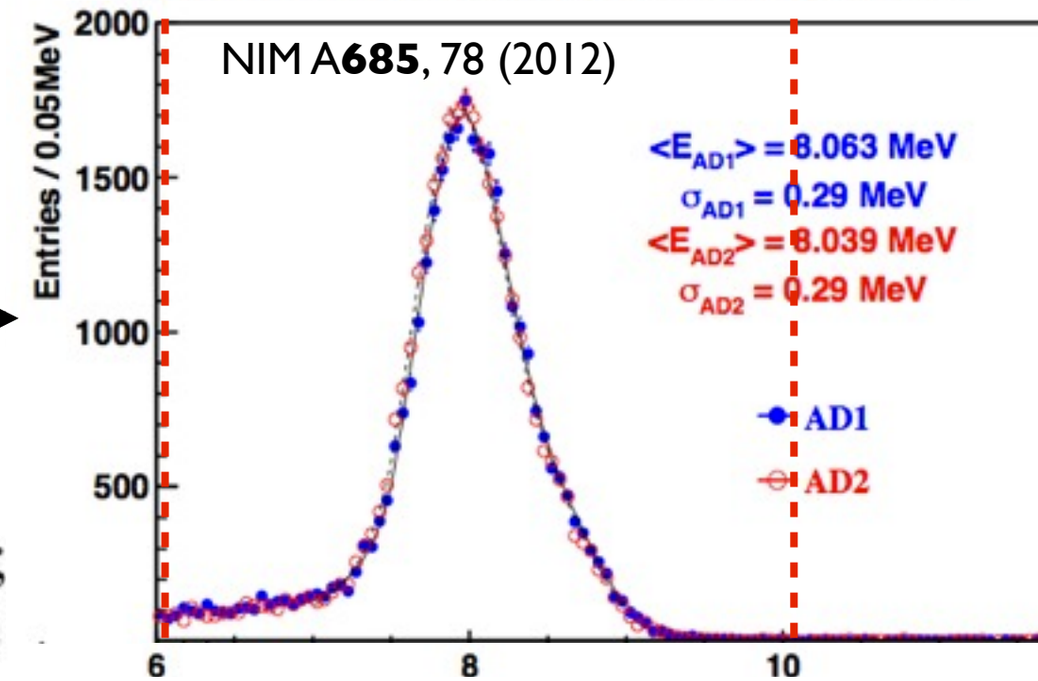
Detection Method

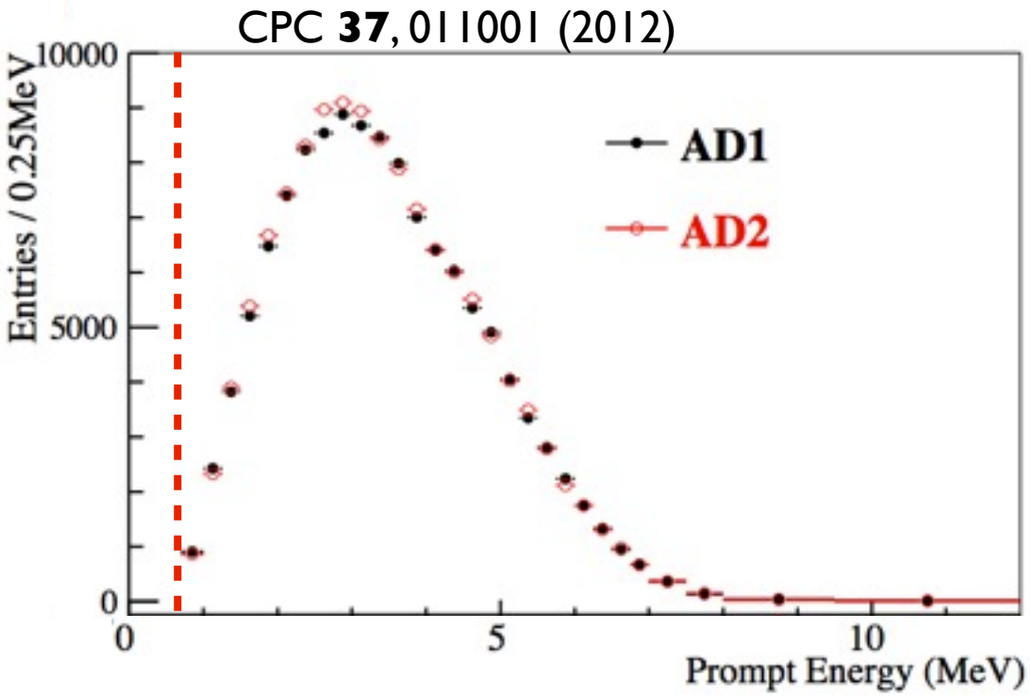
- 0.1% Gd-doped liquid scintillator (GdLS) as an inverse-beta target

$$\bar{\nu}_e + p \rightarrow e^+ + n$$



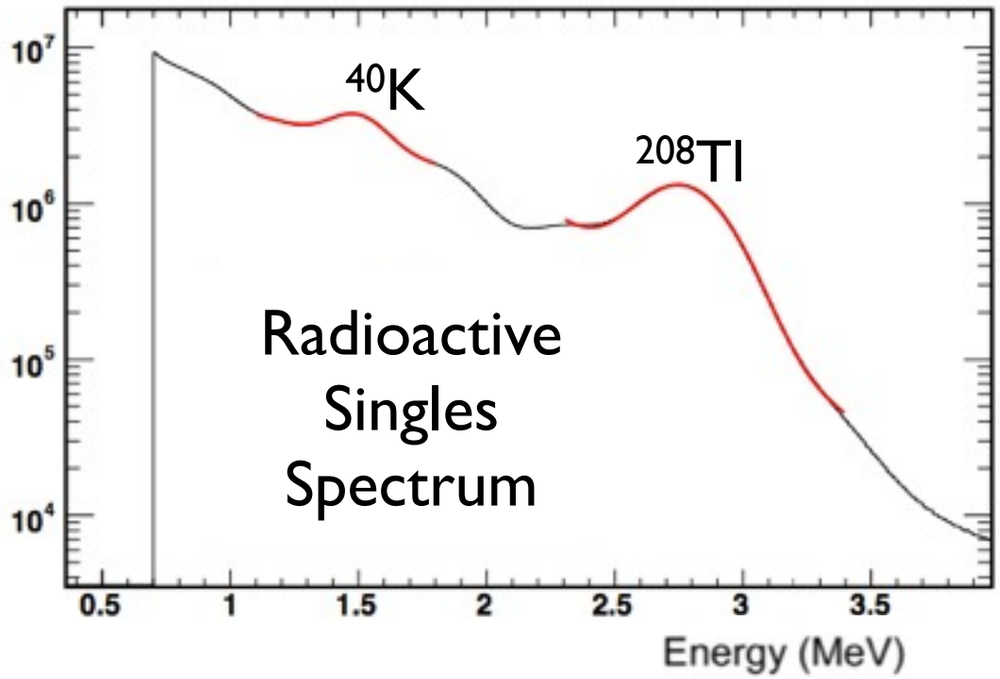
$$E_{e^+} = E_{\bar{\nu}_e} - 1.29\text{MeV}$$

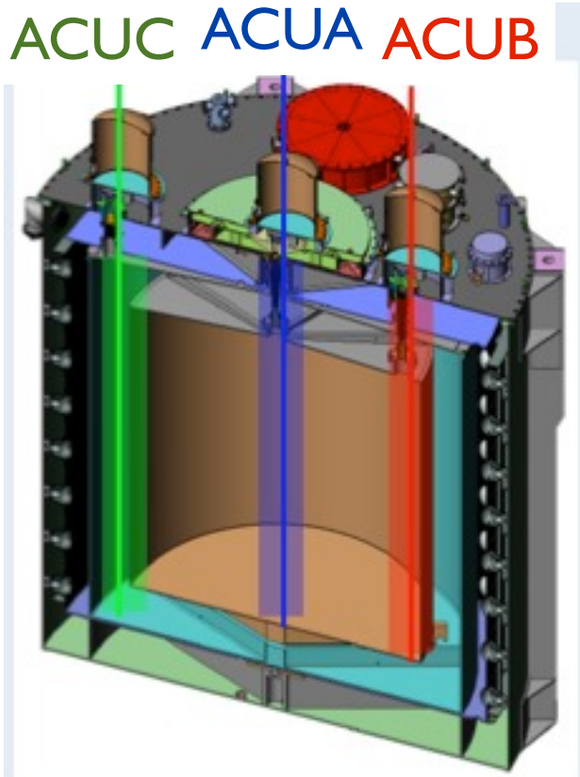




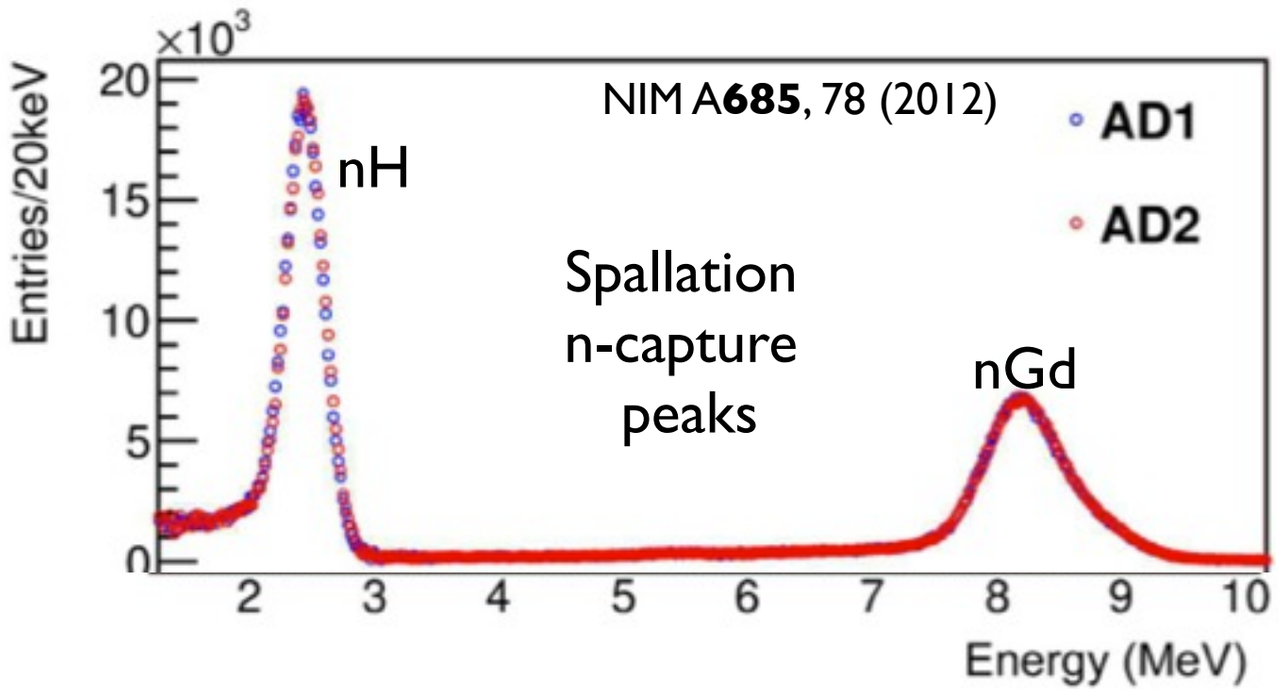
Energy Scale Calibration

- Use many types of data to translate collected light into particle energy
  - Automated Calibration Units (ACUs)
    - ^{68}Ge, ^{60}Co, AmC neutrons
  - Spallation Neutrons
    - gammas in LS, GdLS
  - Radioactive backgrounds
    - Gammas, betas, and alphas
  - Special Calibrations
    - gammas anywhere in GdLS





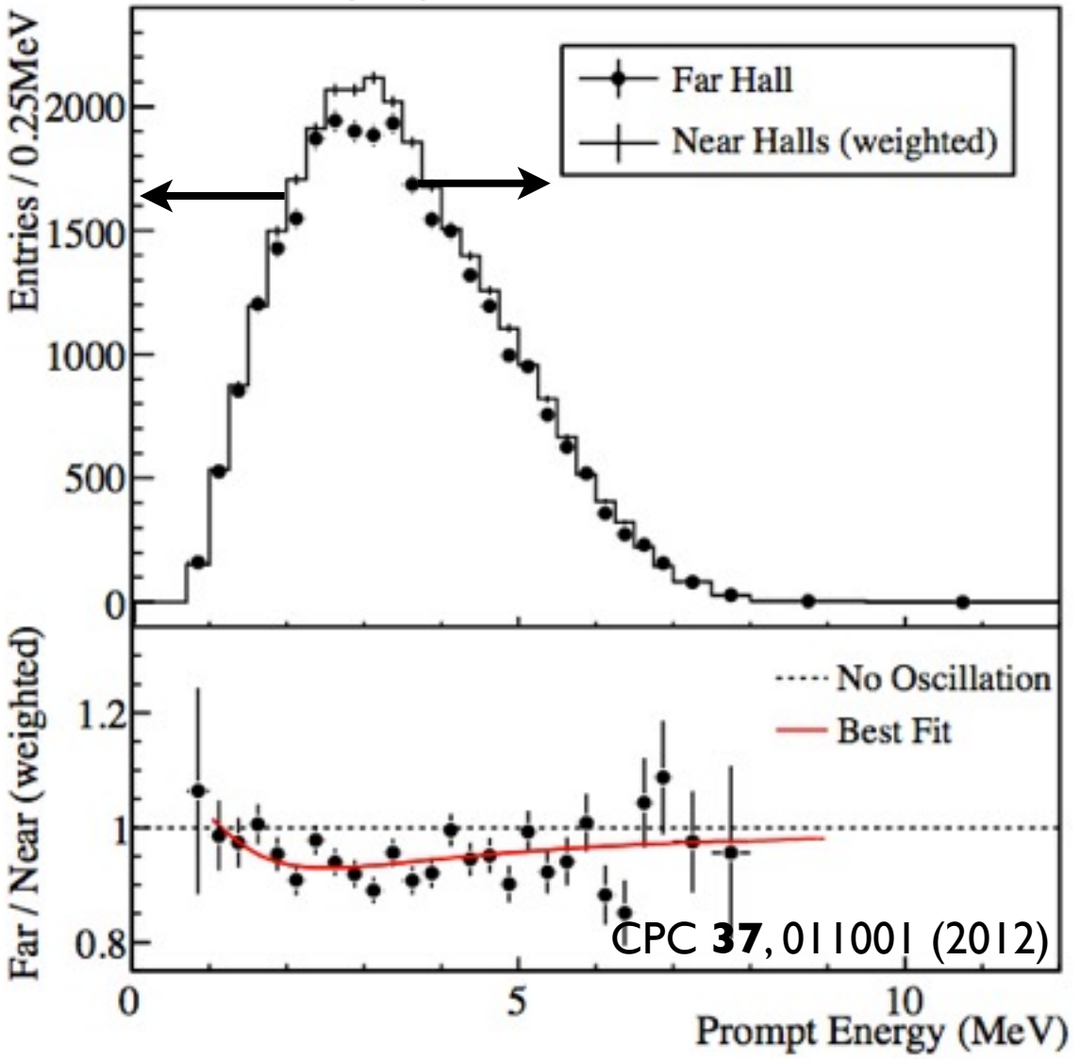
- Slightly non-uniform with position and total charge



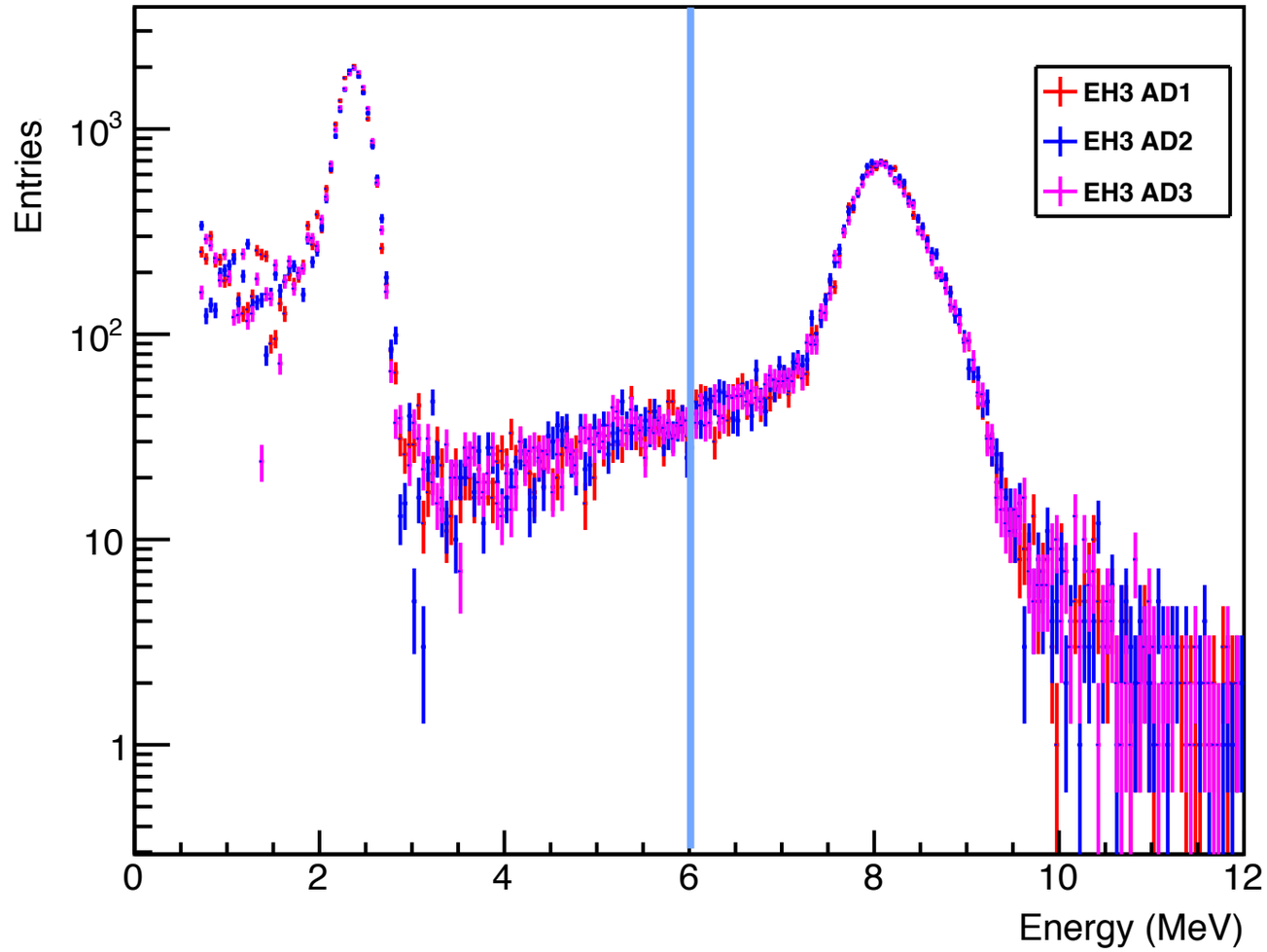
Relative Energy Scale Calibration

- **Are reconstructed energies the same in all detectors?**
  - Most important energy scale consideration for our relative θ_{13} measurement
  - Relative shift distorts near/far spectral asymmetry (can mimic oscillation!)
  - Important for energy cut efficiencies

Prompt Spectra: Near and Far Sites

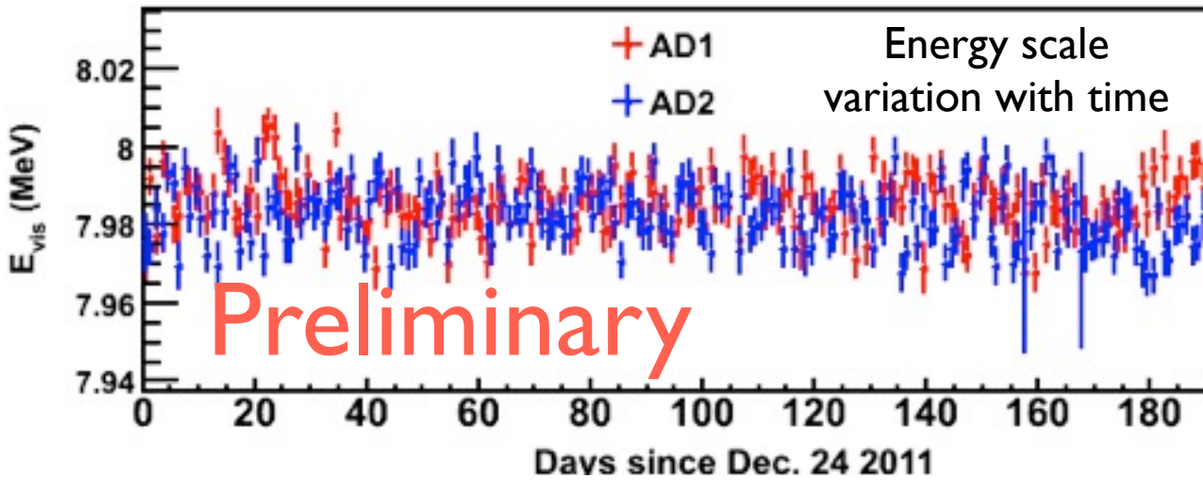


Delayed Spectra: Far Site

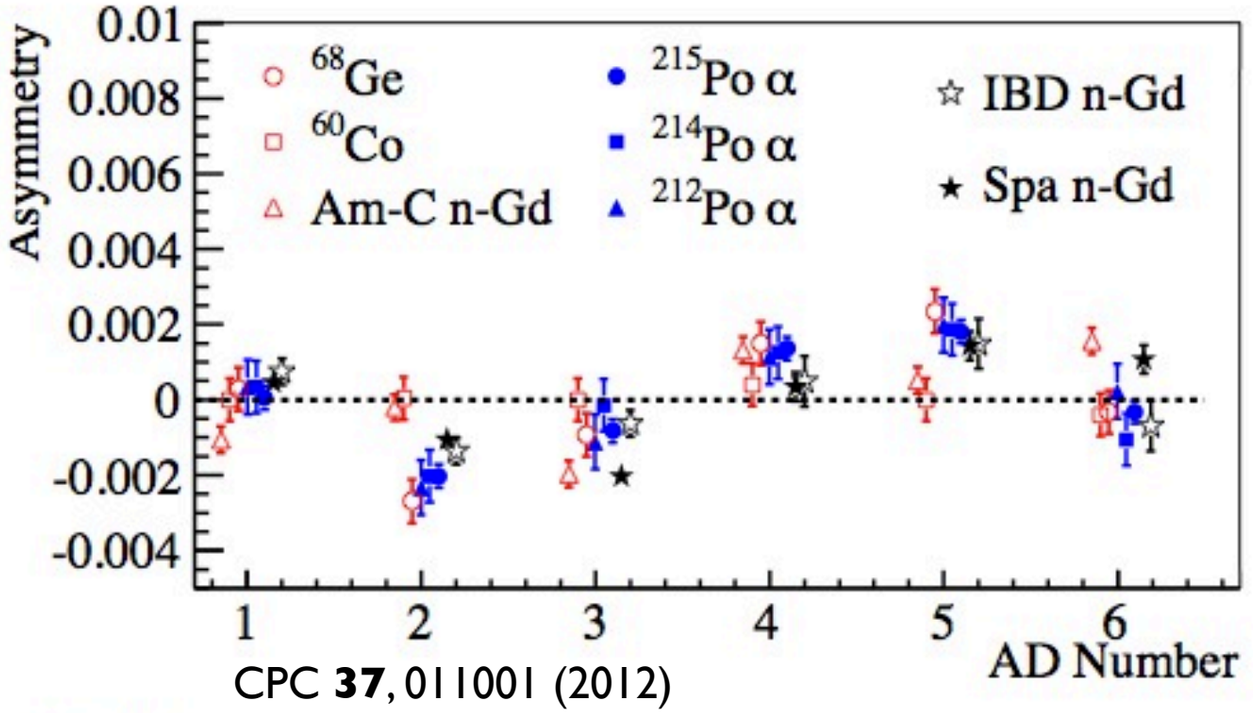


Relative Energy Scale Calibration

- Relative time variation very small (<0.1%)

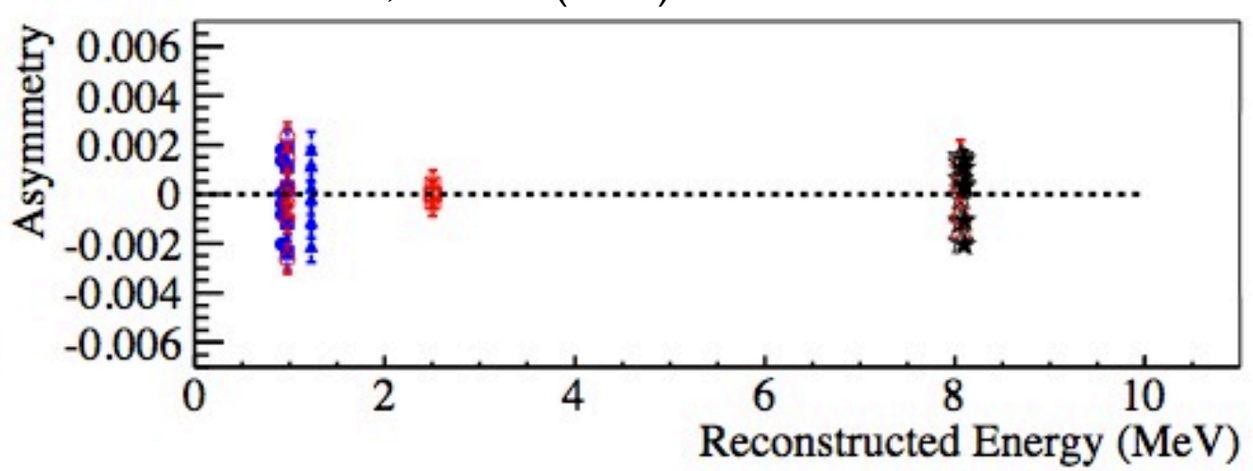


- Examine per-AD deviation from mean e-scale
  - No clear dependence on AD, energy, or position distribution



CPC **37**, 011001 (2012)

- Conservatively estimate relative energy scale uncertainty as 0.5%
  - Leads to 0.12% delayed energy cut efficiency
  - Previously expected to be largest relative detector systematic at 0.3%!!

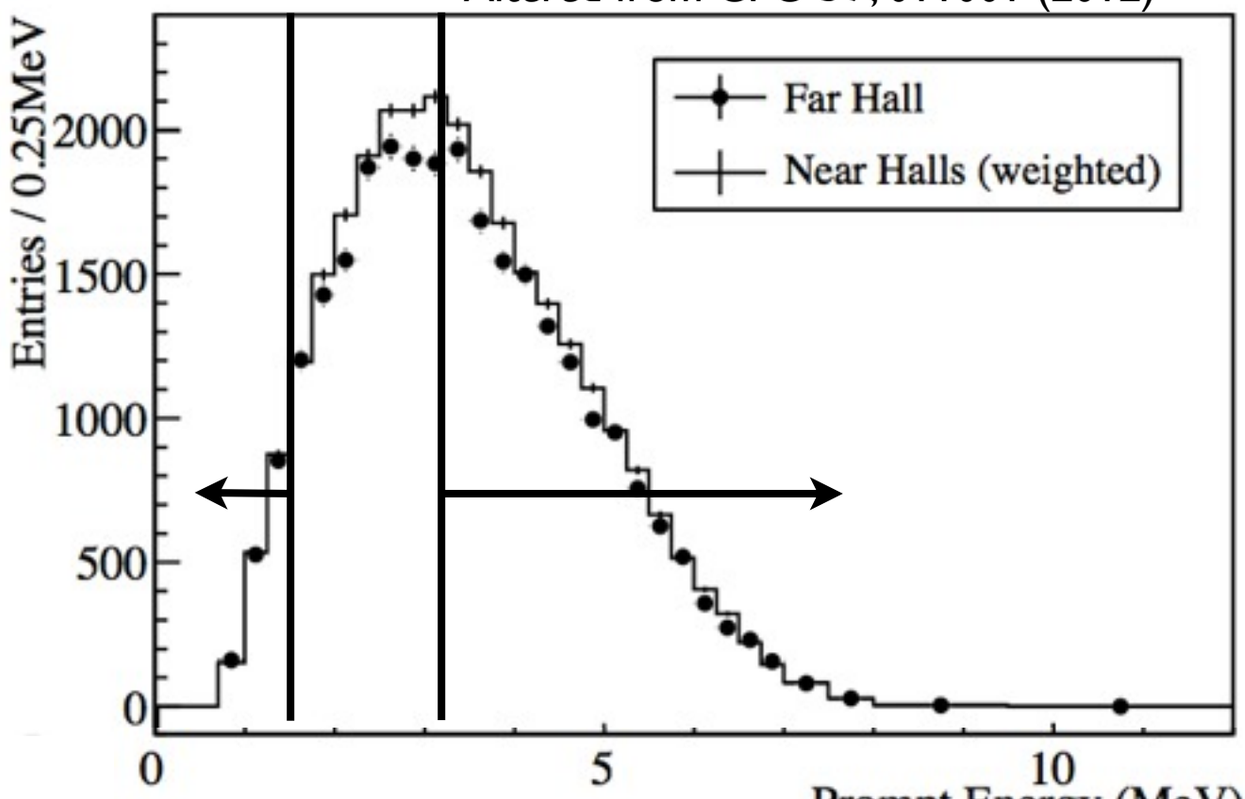


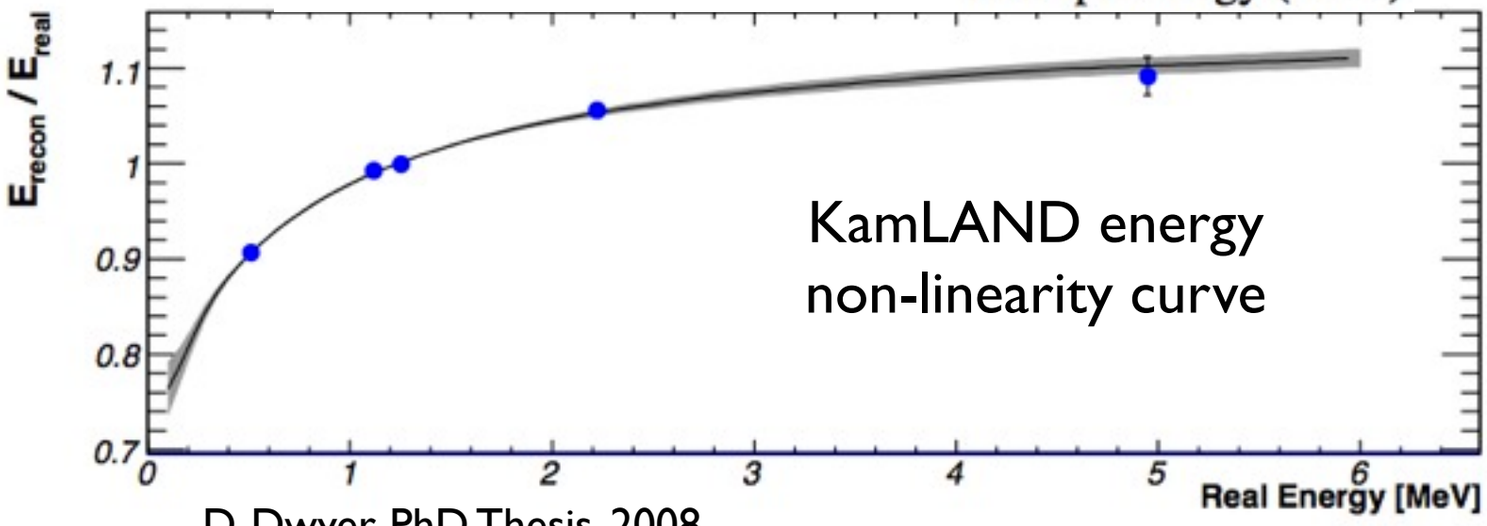
Absolute Energy Scale Calibration

- Does reconstructed energy match true energy?
  - Less important for θ_{13}: relative measurement
  - More important for absolute spectral measurement

- Reconstructed energy scale will not be linear
  - Scintillator quenching
  - Cerenkov light production
  - Non-linearities in electronics

Altered from CPC **37**, 011001 (2012)



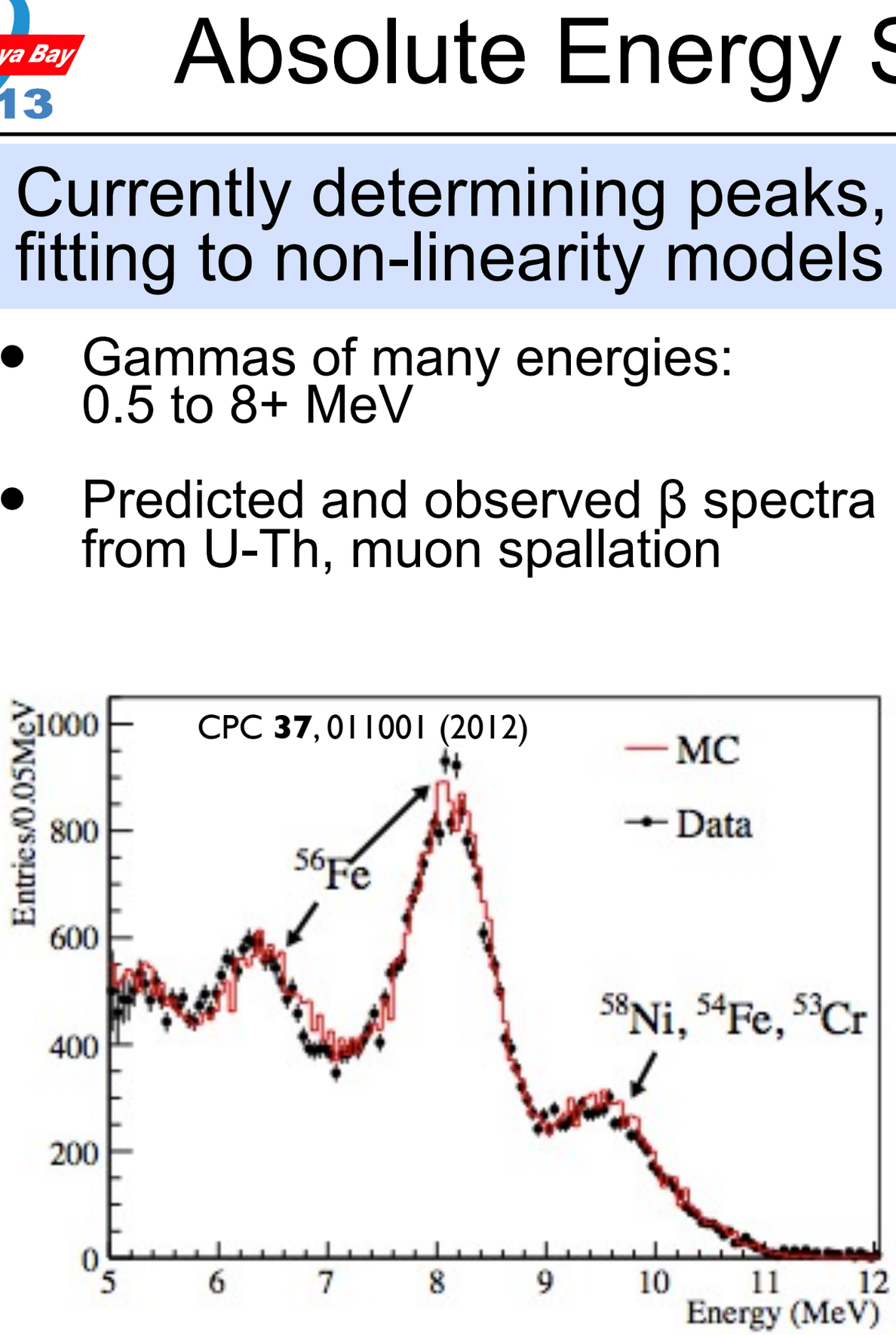


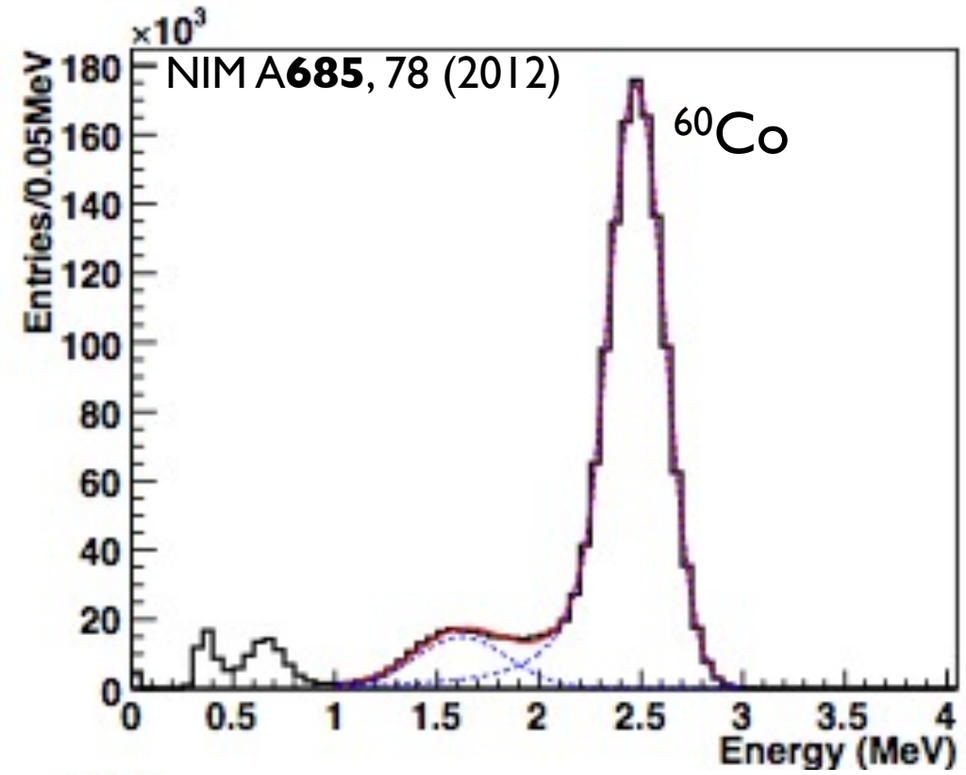
KamLAND energy non-linearity curve

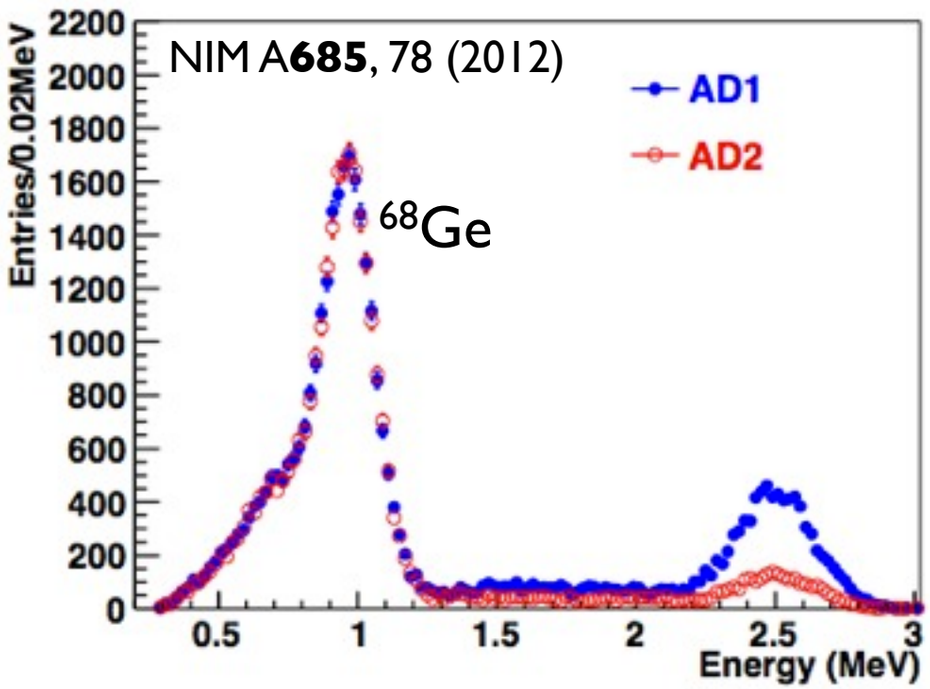
D. Dwyer, PhD Thesis, 2008

Absolute Energy Scale Calibration

- Currently determining peaks, spectra for variety of sources, fitting to non-linearity models
  - Gammas of many energies: 0.5 to 8+ MeV
  - Predicted and observed β spectra from U-Th, muon spallation



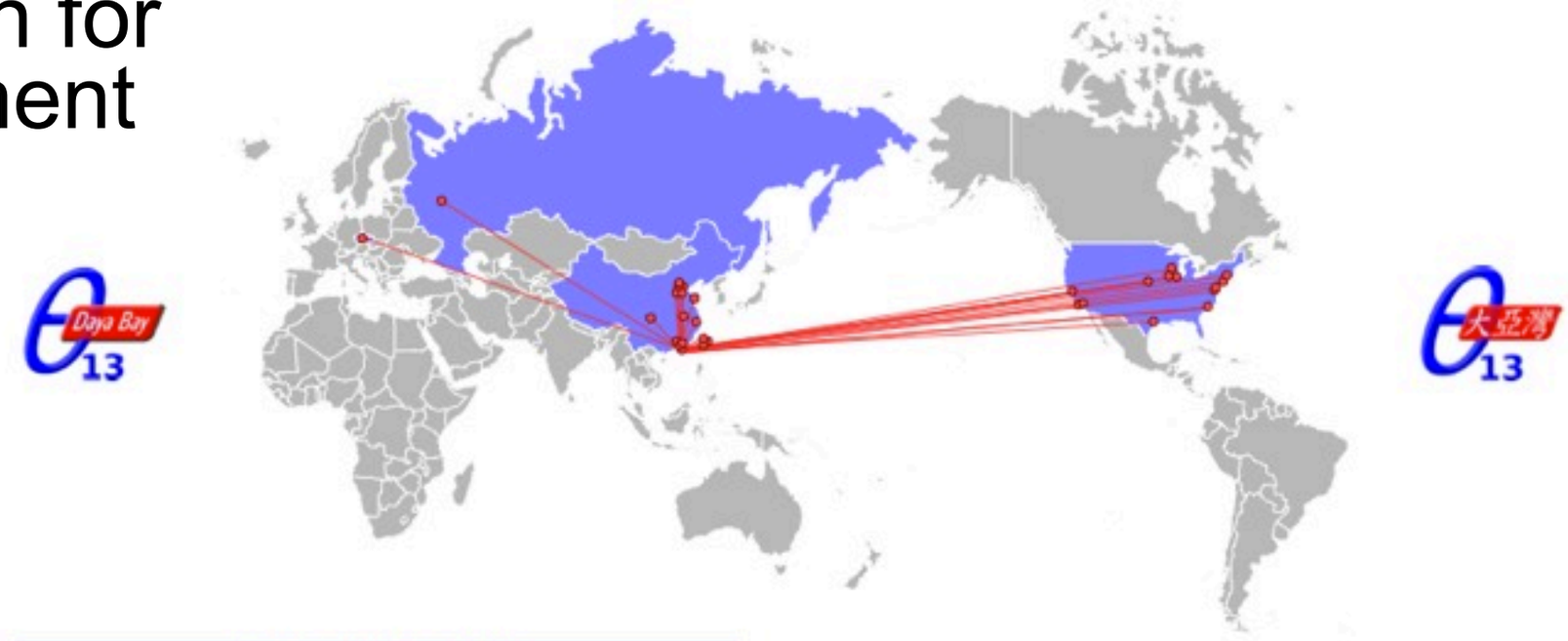




Summary

- Daya Bay has world's most precise θ_{13} measurement, continues to take data, and has new results coming soon!
- Relative energy scale uncertainty important for θ_{13}, determined to be less than 0.5%
- Absolute calibration for spectral measurement is underway

More Daya Bay Talks	
Shih Kai Lin	Next!
Henoch Wong	Next!
Mike McFarlane	B9
Robert McKeown	R3



North America (16)

Brookhaven Natl Lab, Cal Tech, Cincinnati, Houston, Illinois Institute of Technology, Iowa State, Lawrence Berkeley Natl Lab, Princeton, Rensselaer Polytech, UC Berkeley, UCLA, Wisconsin, William & Mary, Virginia Tech, Illinois, Siena College

Europe (2)

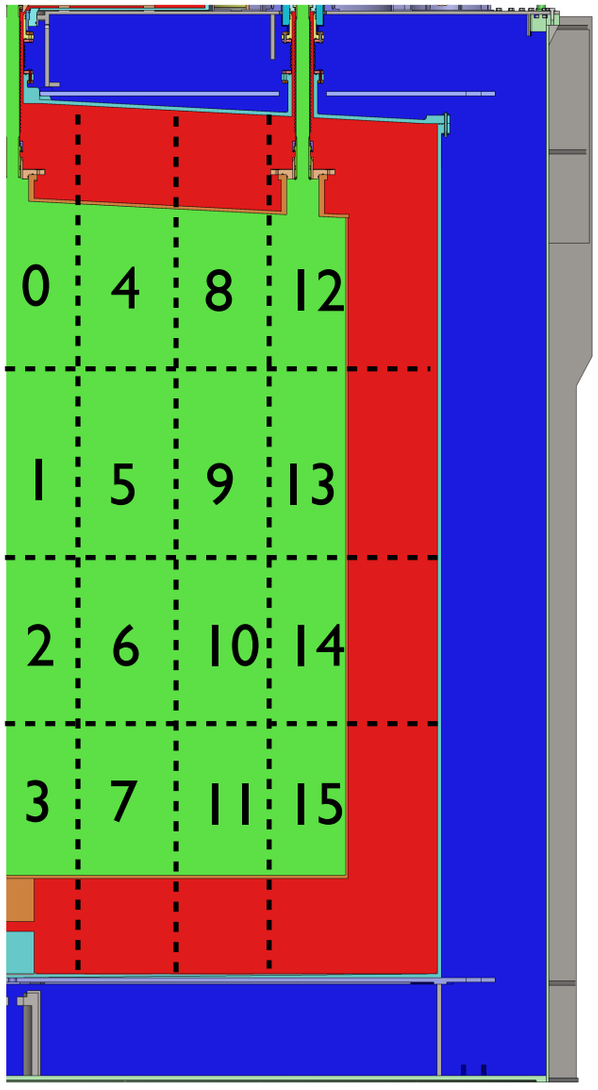
Charles University, Dubna

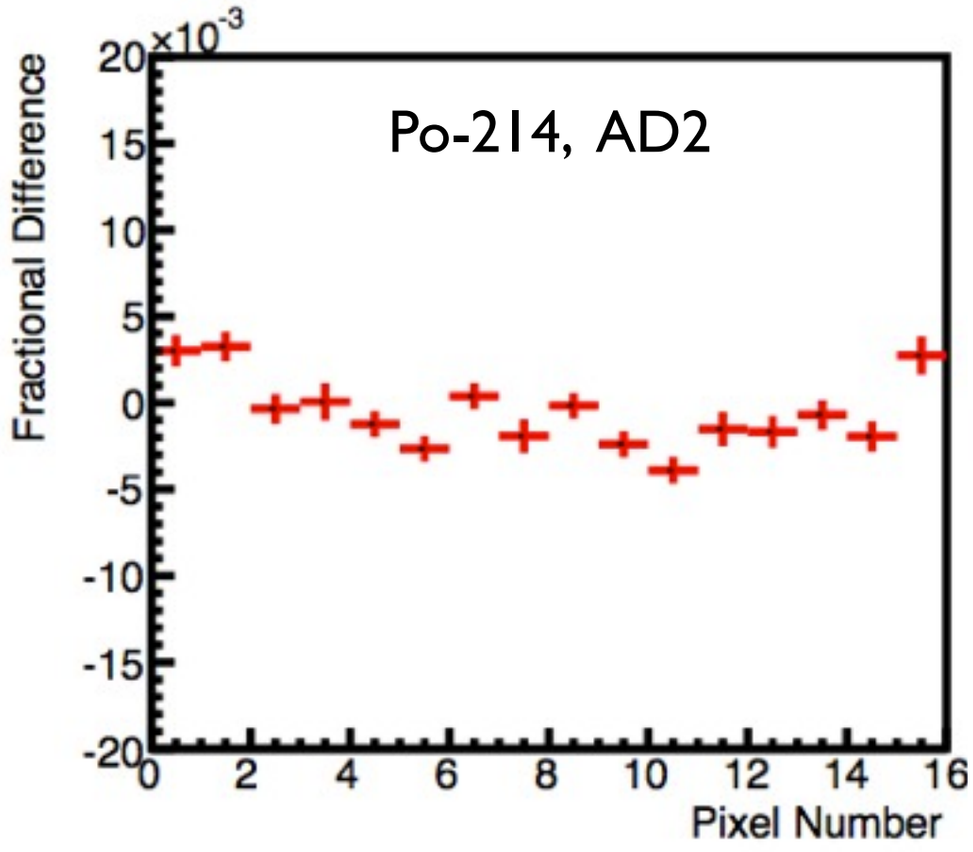
Asia (20)

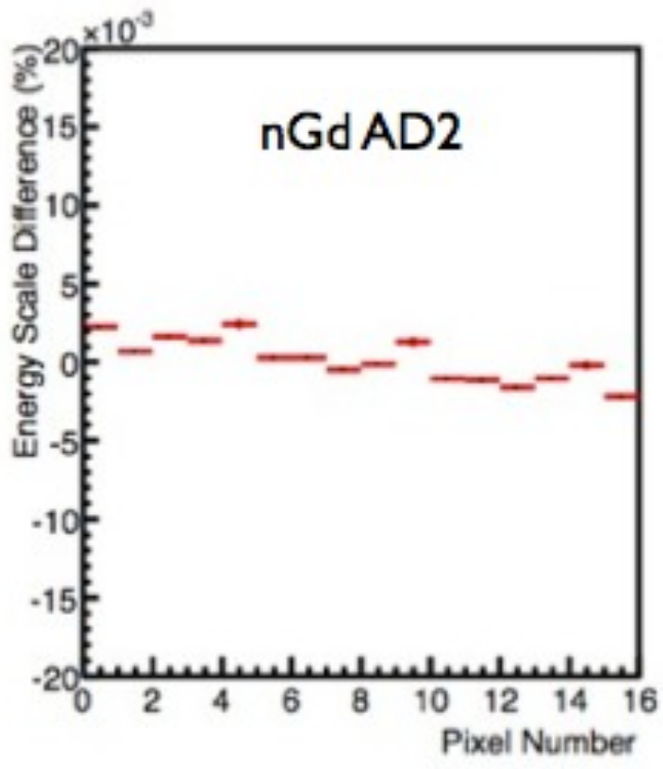
IHEP, Beijing Normal Univ., Chengdu Univ. of Sci and Tech, CGNPG, CIAE, Dongguan Polytech, Nanjing Univ., Nankai Univ., NCEPU, Shandong Univ., Shanghai Jiao Tong Univ., Shenzhen Univ., Tsinghua Univ., USTC, Zhongshan Univ., Univ. of Hong Kong, Chinese Univ. of Hong Kong, National Taiwan Univ., National Chiao Tung Univ., National United Univ.

Relative Energy Scale Calibration

- Position-dependence differences:
  - Look at AD1/AD2 difference in n-Gd energy peak versus location
  - Can sample entire target volume, rather than only ACU z-axes!





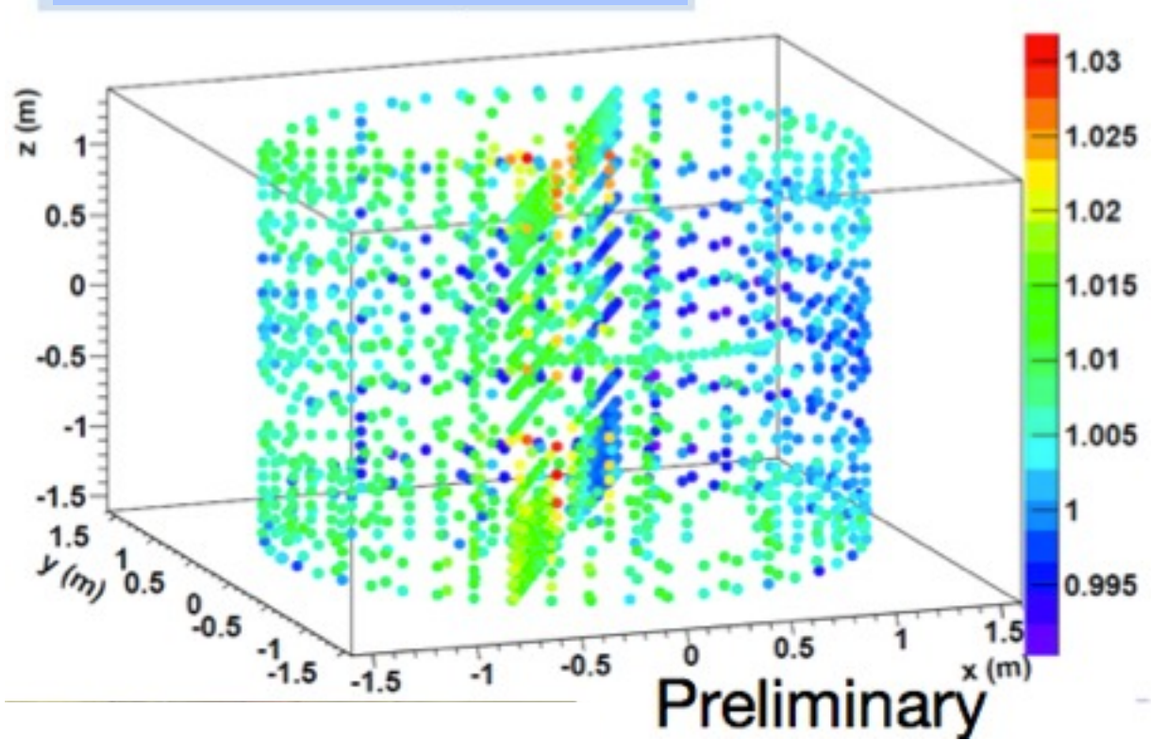


- All regions of target have identical energy scale with an RMS of 0.25%

Absolute Energy Scale Calibration

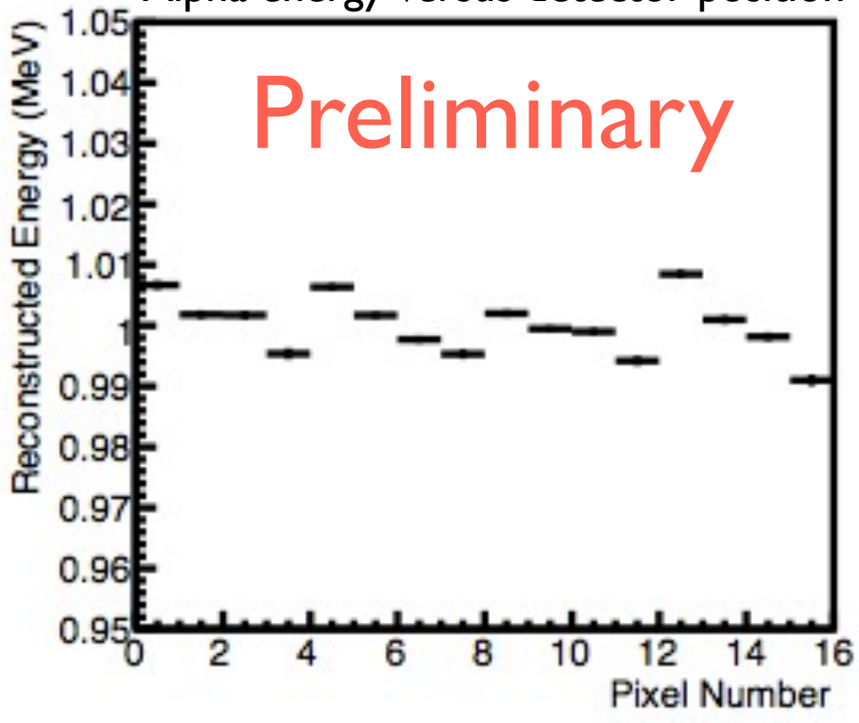
- Have also investigated non-uniformities
  - Spallation neutrons and U-Th alphas
  - Manual Calibration System with articulating arm

3D map of detector response with MCS



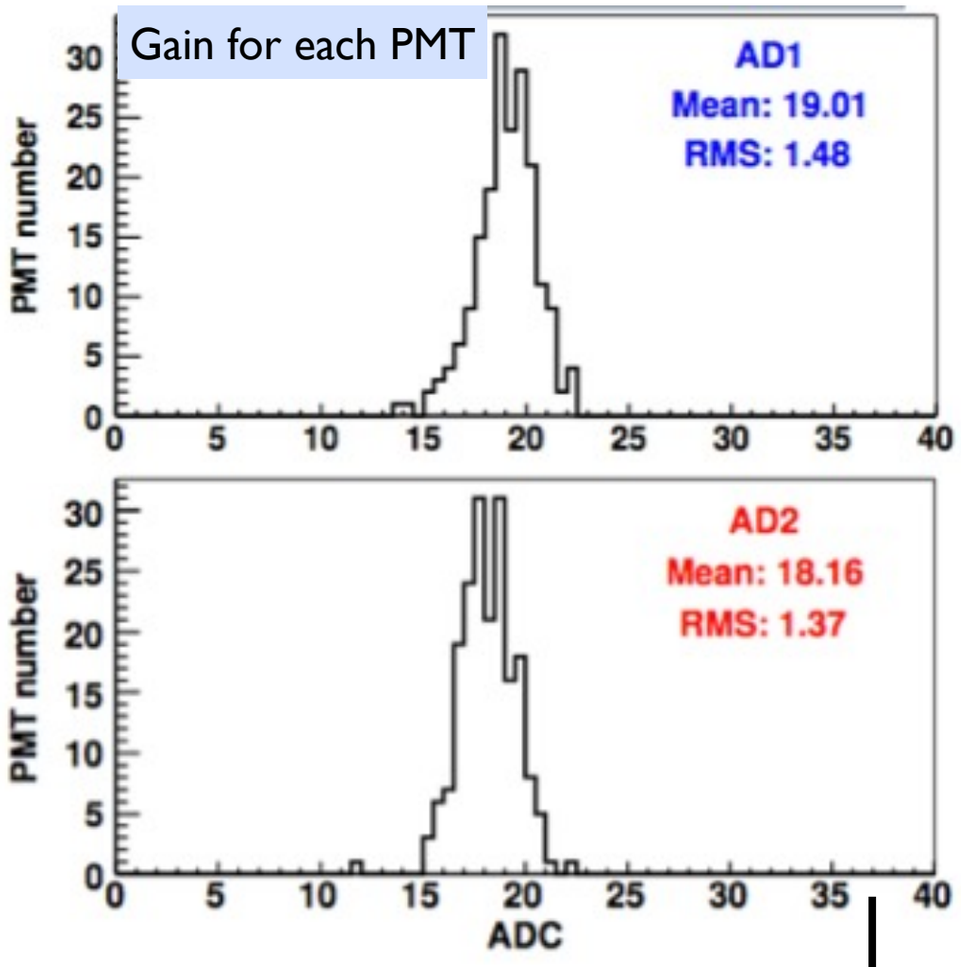
MCS System

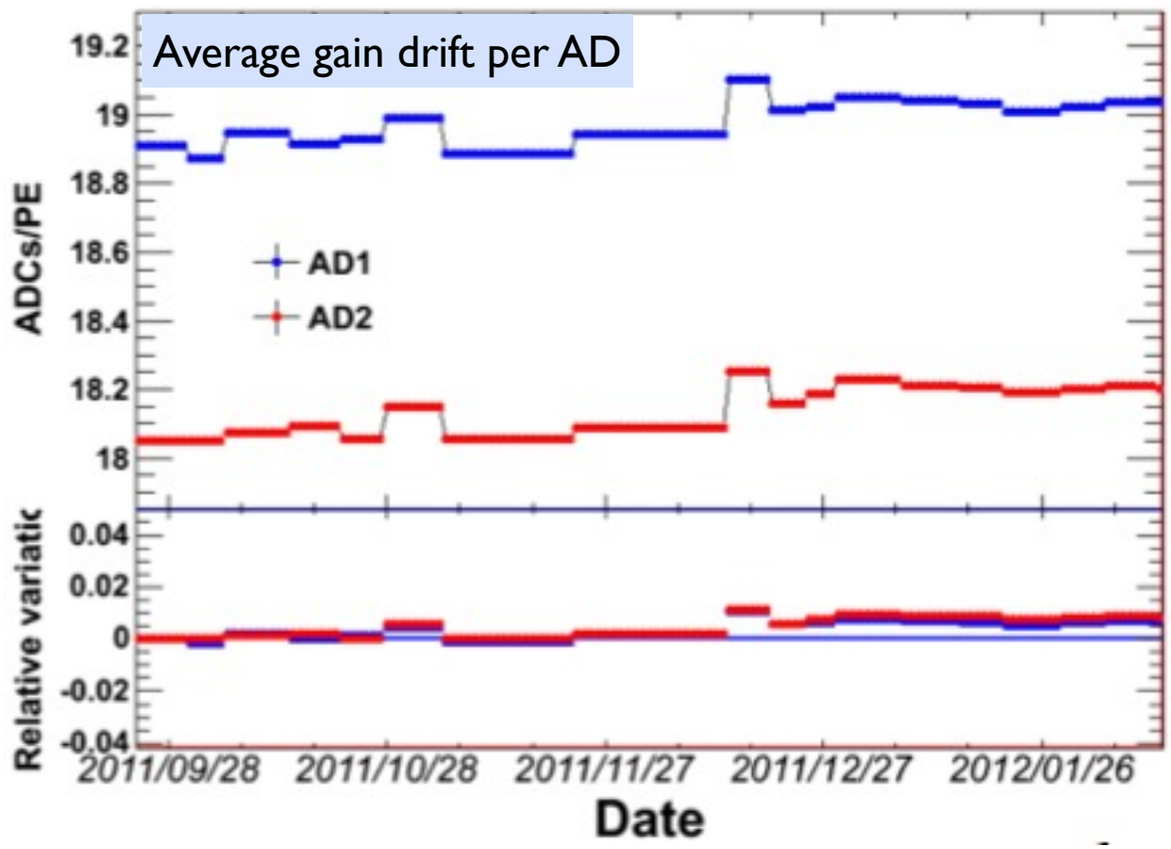
Alpha energy versus detector position

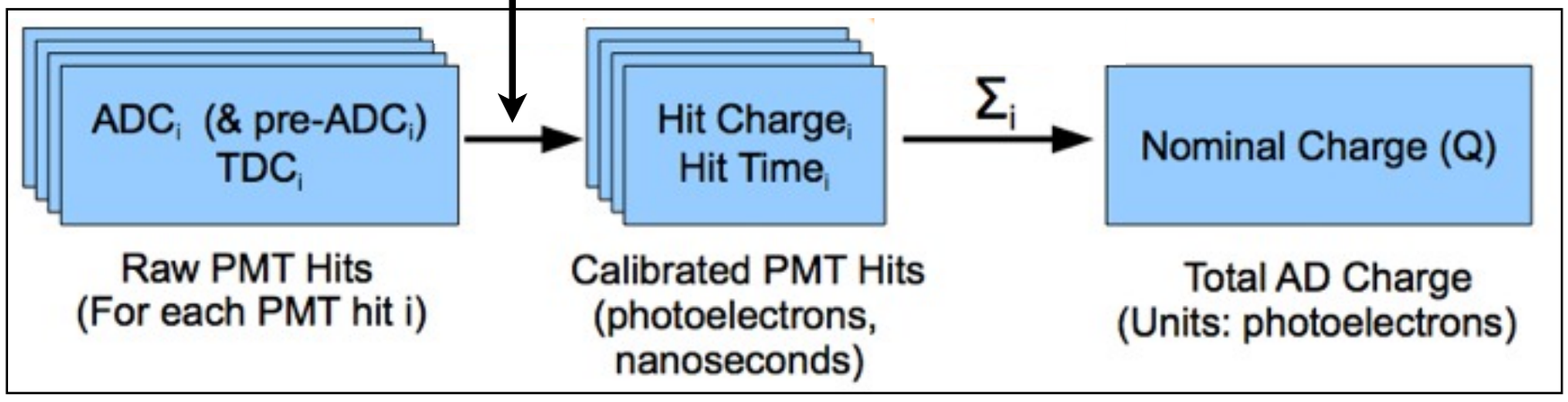


Calibration: PMTs and Electronics

- PMT calibration: removes time drift from PMTs and electronics
  - Calibrate voltage per photoelecton (gain): fitting PMT's single-photoelectron peak



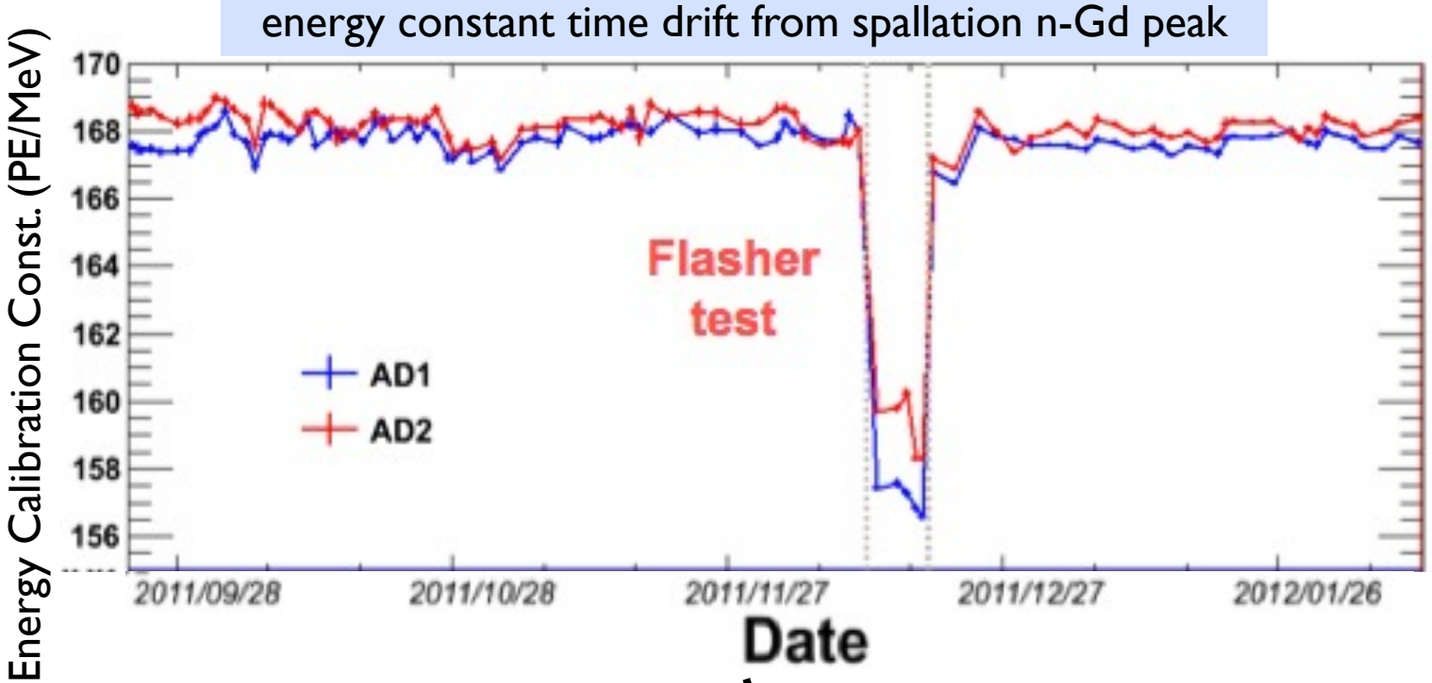




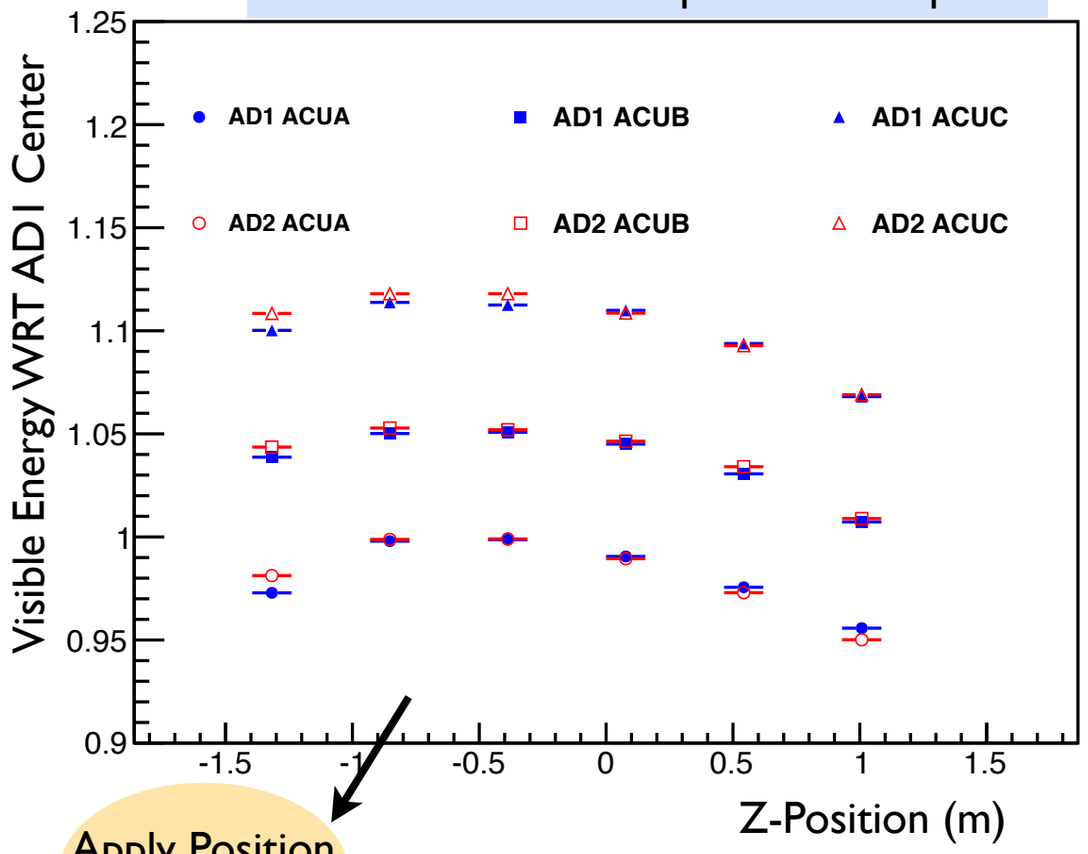
Energy Scale Calibration

- Provides consistent measure of energy based on the 8MeV spallation n-Gd peak
- Removes position, time variations in light collection
- Allows for constant monitoring of energy scale during physics runs

energy constant time drift from spallation n-Gd peak



Position-variation of spallation n-H peak



Apply Time Correction

Apply Position Correction

Nominal Charge (Q) → Raw Visible Energy (E_{vis}) → Reconstructed Energy (E_{rec})

Units: Photoelectrons | Units: ~MeV | Units: MeV

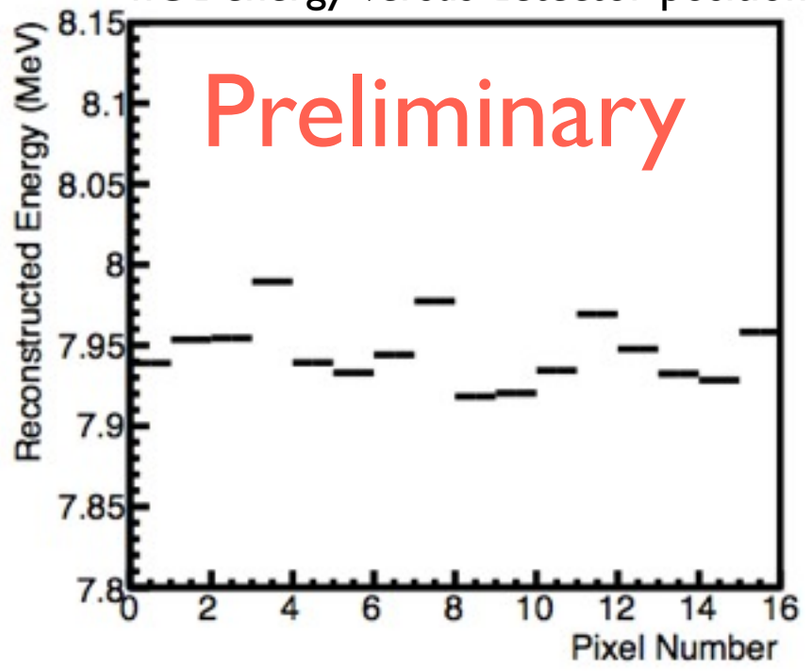
Absolute Energy Scale Calibration

- Have also investigated non-uniformities
  - Spallation neutrons and U-Th alphas
  - Manual Calibration System with articulating arm

3D map of detector response with MCS

MCS System

nGd energy versus detector position



Alpha energy versus detector position